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OXYGEN ISOTOPIC COMPOSITIONS OF SEVERAL ANTARCTIC METEORITES

Toshiko K. MAYEDA[1], Robert N. CLAYTON[2] and Keizo YANAI[3]

[1]*Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637, U.S.A.*
[2]*Enrico Fermi Institute, Department of Chemistry, Department of the Geophysical Sciences, University of Chicago, Chicago, Illinois 60637, U.S.A.*
[3]*National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173*

Abstract: Oxygen isotopic compositions are reported for seven carbonaceous chondrites, seven ordinary chondrites, two enstatite chondrites, three lunar meteorites, and twelve achondrites. Three of the achondrites (ALH-77081, Y-74063, and Y-74025) do not belong to known groups; the first two of these are related to Acapulco. Two L-group equilibrated ordinary chondrites (Y-75097 and Y-793241) contain xenoliths with isotopic compositions similar to H chondrites. Among the carbonaceous chondrites, the distinction between C1 and C2 chondrites is ambiguous.

1. Introduction

The most important benefit of the collection of Antarctic meteorites is in providing meteorite types that are not represented in existing museum collections. Outstanding examples are the discoveries of meteorites of lunar origin and of possible martian origin. A potent characteristic for recognition of meteorite types and their genetic interrelationships is the isotopic composition of oxygen. Oxygen isotope data on Antarctic meteorites have been discussed in the Proceedings of Symposia on Antarctic Meteorites (ONUMA *et al.*, 1978, 1983; CLAYTON *et al.*, 1984). This paper presents new data on several different meteorite types, including carbonaceous, ordinary and enstatite chondrites, calcium-rich and calcium-poor achondrites, lunar meteorites, and some previously unclassified meteorites.

2. Analytical Methods

Oxygen extraction and isotopic analyses were done by the methods described by CLAYTON and MAYEDA (1963, 1983). Isotopic data are presented as permil (‰, parts per thousand) deviations of $^{18}O/^{16}O$ and $^{17}O/^{16}O$ ratios with respect to the SMOW isotope standard. Analytical uncertainties are typically about 0.1‰. Weathering of meteorites in the Antarctic environment is potentially a serious problem for oxygen isotope studies, and in some cases leads to substantial contamination by isotopically light oxygen. Only one sample in the present study (Yamato-74370) appears to have been greatly affected by weathering.

3. Carbonaceous Chondrites

The oxygen isotopic compositions of carbonaceous chondrites fall into four separate groups, corresponding to C1 (CI), C2 (CM), C3 (CO and CV), and CR (Renazzo and Al Rais) (CLAYTON *et al.*, 1976; CLAYTON and MAYEDA, 1977, 1984). Isotopic data for seven Antarctic carbonaceous chondrites are given in Table 1 and are plotted in Fig. 1. The previously observed groupings of isotopic composition are found, but there is not exact correspondence with the assigned meteorite class. Belgica-7904, classified as C2 (YANAI and KOJIMA, 1985), falls at the uppermost end of the C1 isotopic range, whereas Y-82042, classified as C1, falls in the C2 isotopic range, close to Y-793321 and

Table 1. Oxygen isotopic compositions of carbonaceous chondrites.

Sample No.	Catalog class	Isotopic group	$\delta^{18}O$ (‰ rel. to SMOW)	$\delta^{17}O$ (‰ rel. to SMOW)	
B-7904	C2	C1	+21.07	+10.91	
Y-82162	C	C1	+21.56	+11.59	
Y-793321	C2	C2	+10.62	+2.58	
Y-82042	C1	C2	+8.49	+2.39	
Y-790112	CR	CR	+2.39	−0.32	
Y-693	C4	CO	−0.61	−4.49	whole-rock
			−4.00	−7.01	chondrule
			+1.94	−2.88	plagioclase
			−1.34	−4.79	olivine
			−3.50	−5.99	magnetite
Y-82104	C5	CO	−1.07	−4.86	

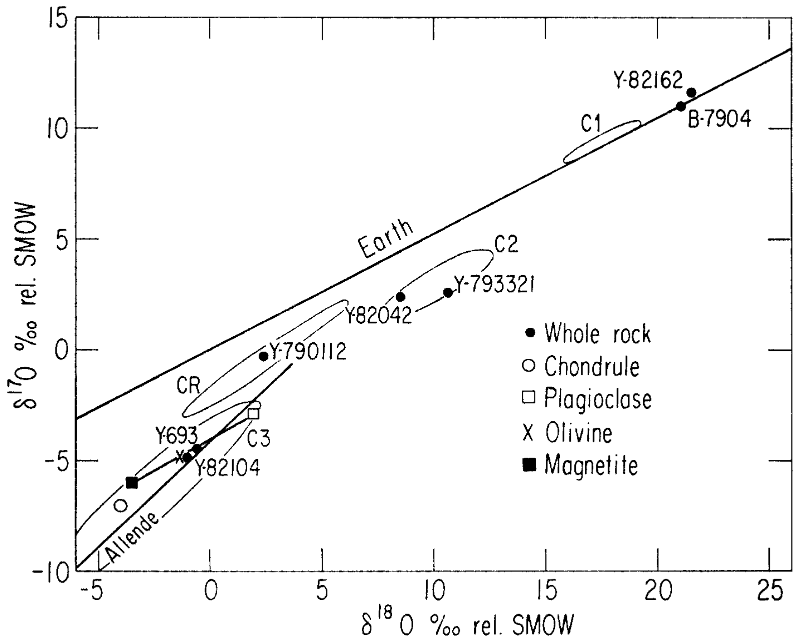

Fig. 1. Oxygen isotopic compositions of carbonaceous chondrites. Typical C1 chondrites plot near the terrestrial line with $\delta^{18}O$=18–20‰; C2 chondrites plot below the terrestrial line with $\delta^{18}O$ near 8‰; C3 chondrites fall along a slope-1 line with low values of $\delta^{18}O$ and $\delta^{17}O$; CR chondrites fall between the terrestrial line and the C3 line.

Murchison. Y-82162, classified only as a carbonaceous chondrite, falls in the C1 range. The oxygen isotopic compositions of the low-temperature phases in C1 and C2 chondrites (phyllosilicates, magnetite, carbonates) are probably determined by low-temperature aqueous alteration of pre-existing anhydrous silicates (CLAYTON and MAYEDA, 1984). The isotopic compositions observed depend on the temperature of alteration (typically 0–150°C), and the relative amounts of water and rock, with C1 alteration having taken place under warmer and wetter conditions than C2. Since temperature and water/rock ratio may be decoupled, and may vary continuously within the inferred range, we may expect to find a continuum of chemical, mineralogical, and isotopic properties from C1 to C2 chondrites.

Y-790112, classified as a CR meteorite, has an isotopic composition which lies within the field defined by various separated components of Renazzo, and is thus distinct from other carbonaceous chondrites.

Y-693 and Y-82104, classed as C4 and C5, respectively, fall within the CO oxygen isotope group, as do other metamorphosed carbonaceous chondrites, such as Coolidge and Karoonda (CLAYTON *et al.*, 1977). The isotopic compositions of separated mineral phases from Y-693 fall along a fractionation line, indicating internal equilibration during metamorphism. The plagioclase-magnetite ^{18}O fractionation of 5.4‰ is similar to the value of 5.8‰ in Karoonda, and corresponds to a temperature of equilibration of about 740°C (MATTHEWS *et al.*, 1983). The isotopic composition of an olivine-rich chondrule from Y-693 shows that isotopic equilibrium has not been established among all phases in the meteorite. A similar observation was made for Karoonda (CLAYTON *et al.*, 1977).

4. Ordinary Chondrites

Isotopic data for eight ordinary chondrites are presented in Table 2. In all cases, the compositions fall within the ranges previously observed for H, L, and LL chondrites (ONUMA *et al.*, 1978).

Two especially interesting meteorites are Y-75097 and Y-793241, both L6 chondrites which contain cm-sized dunitic inclusions. An inclusion in Y-75097 has been described in detail, and compared with the dunitic achondrite, Brachina (YANAI *et al.*, 1983). The oxygen isotopic compositions of the host meteorite have normal L chondritic values, whereas the inclusions plot well away from the L chondrite field, and near the field of H chondrites (Fig. 2). The compositions are not similar to those of any known achondrites, including the dunites Brachina and Chassigny (CLAYTON and MAYEDA, 1983). In fact, the inclusion in Y-793241 has a composition significantly below the H-chondrite field in Fig. 2, implying a source material unlike any known meteorite type. Although the major element chemical compositions of olivine in the clasts and host are the same (YANAI *et al.*, 1983), the isotopic compositions appear to rule out derivation of the clast material by differentiation of L- or LL-type precursors. The same host/clast relationship has been observed in the L6 chondrite Barwell by HUTCHISON *et al.* (1986), who conclude that the clast has an igneous origin.

Table 2. Oxygen isotopic compositions of chondrites and achondrites.

Class	Sample No.	$\delta^{18}O$ (‰ rel. to SMOW)	$\delta^{17}O$	δ^{17}–$0.52\delta^{18}$	
Ordinary chondrites					
H5	Y-695	+4.28	+3.01	+0.78	
H5	Y-696	+4.45	+3.19	+0.88	
H6	Y-694	+4.64	+3.25	+0.84	
L6	Y-75097	+4.53	+3.55	+1.19	host
		+4.54	+3.05	+0.69	clast
L6	Y-793241	+4.32	+3.30	+1.05	host
		+3.75	+2.42	+0.47	clast
		+4.02	+2.48	+0.39	clast
LL7	Y-74160	+4.84	+3.74	+1.22	
LL	Y-79064	+6.21	+4.35	+1.12	
Enstatite chondrites					
E3	Y-691	+4.83	+2.46	−0.05	
E4	Y-74370	+1.30	+0.43	−0.30	weathered
Achondrites					
Eucrite	Y-791192	+3.59	+1.66	−0.20	
Howardite	Y-7308	+3.17	+1.33	−0.32	
Diogenite	Y-692	+3.32	+1.37	−0.36	
Diogenite	Y-74013	+3.07	+1.27	−0.33	
Diogenite	Y-74097	+3.14	+1.36	−0.27	
Diogenite	Y-75032	+3.08	+1.31	−0.29	
Diogenite	ALH-77256	+3.34	+1.62	−0.12	
Diogenite	Y-791193	+3.53	+1.72	−0.12	
Aubrite	ALH-78113	+5.35	+2.86	+0.08	
Lunar	Y-791197	+5.39	+2.88	+0.07	
Lunar	Y-82192	+5.56	+2.85	−0.04	
Lunar	Y-82193	+5.40	+2.80	−0.01	
Acapulcoite	ALH-77081	+3.57	+0.73	−1.13	
Acapulcoite	Y-74063	+3.01	+0.76	−0.80	
Unclassified	Y-74025	+4.21	+1.73	−0.46	

5. Enstatite Chondrites

Isotopic compositions of two unequilibrated enstatite chondrites are given in Table 2. Y-691 was discussed previously in comparison with other enstatite chondrites and achondrites (CLAYTON *et al.*, 1984). Unfortunately, the interesting sample Y-74370 is too severely weathered to permit a satisfactory isotopic analysis.

6. Achondrites

Oxygen isotopic compositions of achondrites fall into five major groups: (1) AMP=eucrites, howardites, diogenites, mesosiderites, and pallasites, (2) SNC=shergottites, nakhlites, and chassignites, (3) aubrites, (4) ureilites, and (5) primitive achondrites, or winonaites (CLAYTON *et al.*, 1976; CLAYTON and MAYEDA, 1978, 1983; MAYEDA and CLAYTON, 1980). The data in Table 2 show that one eucrite, one howardite, and six diogenites all belong to the AMP isotope group. The single aubrite

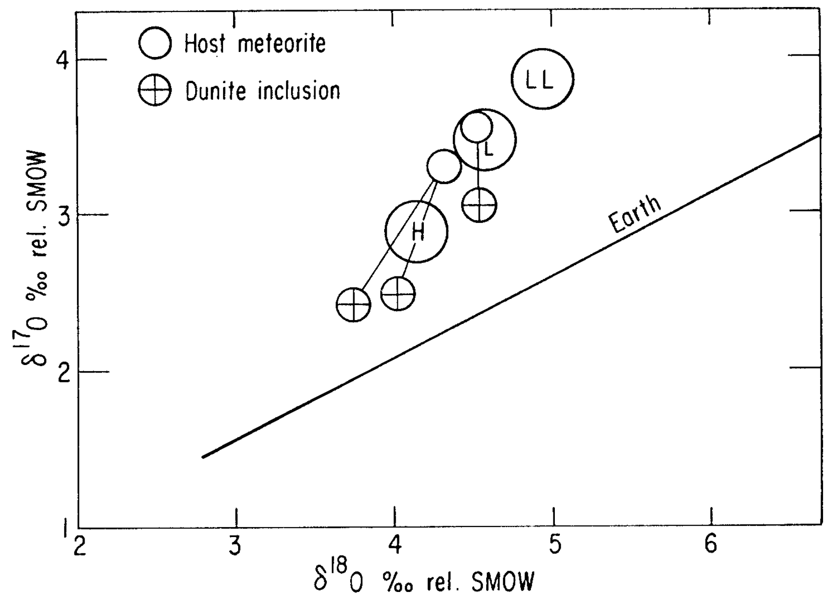

Fig. 2. Oxygen isotopic compositions of two L6 chondrites and their xenoliths. Tie-lines connect the xenolith to the host rock. Large circles indicate the mean compositions of whole-rock H-, L-, and LL-chondrites. The host compositions are normal L-chondrite values, whereas the xenoliths fall near the H-chondrite field.

analyzed, ALH-78113, falls in the previously established aubrite isotope group.

7. Lunar Meteorites

Isotopic compositions of three lunar meteorites are given in Table 2. They all have compositions typical of returned lunar samples (MAYEDA *et al.*, 1983).

8. Unique Meteorites

Oxygen isotope data for three unique meteorites are given in Table 2.

ALH-77081 has an achondritic texture, but has mineral compositions similar to those of H chondrites; it has been classified as H?. Its similarity to Acapulco has been noted (MARVIN and MASON, 1980). Its oxygen isotopic composition is well outside the range of H chondrites, and coincides almost exactly with that of Acapulco (MAYEDA and CLAYTON, 1980). Y-74063 is also achondritic, and has olivine, pyroxene, and plagioclase compositions which are identical to those of ALH-77081 (YANAI and KOJIMA, 1985). Its oxygen isotopic composition is very close to the values for ALH-77081 and Acapulco, the small difference being attributable to the presence of some weathering products. The three meteorites are compared in Table 3. Data on Acapulco are from CHRISTOPHE MICHEL-LEVY and LORIN (1979). These meteorites lie along an ^{16}O mixing trend passing through aubrites, IAB irons, and the iron meteorite Sombrerete. The origin of this relationship is unknown.

Y-74025 is a unique, coarse-grained rock consisting of olivine, pyroxene, and metal. Its oxygen isotopic composition does not fit into any previous group. It oc-

Table 3. Comparison of Acapulco-type achondrites.*

Meteorite	Olivine Fo	Orthopyroxene Fs	Clinopyroxene		
			En	Fs	Wo
Acapulco	10–12.5	11–13	51–55	4.2–5	40.5–43.5
ALH-77081	9.8–11.2	9.4–11.5	52	4	44
Y-74063	10.5–11.4	10.3–12.5	51–52	4.1–4.7	43–45

Meteorite	Plagioclase An	$\delta^{18}O$	$\delta^{17}O$	$\delta^{17}-0.52\delta^{18}$
Acapulco	13	3.73	1.00	−0.94
ALH-77081	12.2–14.4	3.57	0.73	−1.13
Y-74063	13.5	3.01	0.76	−0.80

* Mineralogical data for Acapulco from CHRISTOPHE MICHEL-LEVY and LORIN (1979), for ALH-77081 and Y-74063 from YANAI and KOJIMA (1985).

cupies a position between the AMP achondrites and the silicates in IAB irons, and must represent a separate parent body.

9. Conclusions

The Antarctic meteorites have fulfilled their promise of providing new types of meteorites not previously known, and of providing "partners" for meteorites previously thought to be unique. Oxygen isotopic compositions have proven to be valuable in confirming the identity of lunar meteorites, and in the categorization of chondritic and achondritic meteorites.

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